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Deficit and decline in Australian science; when shall we learn?

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ABSTRACT

Danger exists in using deficit and decline narratives that unsurprisingly have paralleled evidenced declines in research funding for Australian science. While surveys suggest a public lack of understanding of science which is all too often diagnosed and remediated as "dumbness", Australians value science education. Scientists need to be careful when they enter debates about the future direction of science curricula because of the danger in dichotomising the debate in which old pedagogies emerge as retrograde solutions. Solutions exist in new Science, Technology, Engineering and Mathematics (e.g. iSTEM) curricula which are connecting traditionally separated department in schools and in scientists valuing science education and educators as experts. The deficit and decline narrative will continue to be a "dangerous solution" at a time in world history where our young people are more highly educated than ever before with a vastly greater exposure to and experience of science and technology than previous generations. In the current climate where we are suffering a true decline in research funding and disillusionment with careers in science research, we need to take stock and develop new ways to engage society at large with the sciences that are the only hope for sustaining humanity. For Australia's future, we must foster a culture committed to more substantial funding of science research and better education of science teachers.

Key words: Science education, science deficit, science decline, science research, science funding, Australia, science learning

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Introduction

The current rhetoric used by research scientists and science communicators to persuade Australians to take action about science and science learning is an argument based on deficits. Fixations on deficits such as the public lack of understanding of science which is diagnosed and treated as "dumbness" and the emphasis on declines in science enrolments are dangerous strategies which have not abated evidenced declines in research funding for zoology and Australian science. The danger in a deficit and decline rhetoric is similar to the Chicken Little folk tale which tells us the "the sky is falling" creating retrograde solutions for learning sciences such as emphasises on explicit teaching and rote memorisation. This is a century where our young people are more highly educated than ever before, have a broader experience of science and technology than previous populations and require problem solving and critical thinking skills to analyse an exponential growing body of knowledge across the science disciplines. In arguing against a deficit and decline narrative, we may be treading on dangerous ground ourselves because it is not easy to move beyond the deficit narrative. We will present the danger in discussing ways we may enhance the positive view of science, hopefully leading to more substantial funding of science and technology research, as well as better education of science teachers, for Australia's future.

The narrative of deficit

Just how much do the public know and understand about science? The results from the survey commissioned by the Australian Academy of Science on the Australian public understanding of science in July 2010 and May 2013 at first glance gives little room for comfort. This on-line survey asked a series of questions to 1515 Australians aged over 18 selected by gender, age and residential location. The questions were based on a survey designed by the California Academy of Sciences and ranged from exploring the concept of geological scale i.e. did the earliest humans live at the same time as the dinosaurs? to "how long does it take the Earth to go around the Sun?" and other basic facts such as "what percentage of the Earth's water is fresh water?" The survey found that although most Australians have a basic grasp of key scientific facts, there are still large numbers who are unable to correctly answer scientific questions (Wyatt and Stopler 2013). Almost one third of the poll's respondents thought the Earth took between one day and one month to orbit the sun. The proportion of respondents that gave the correct answer was around the same in both years, 61% in 2013 and 59% in 2010, but the proportion of 18-24 year olds answering correctly fell from 74% in 2010 to 62% in 2013, and the proportion of 25-35 year olds answering correctly fell from 67% to 59%. To the question, what percentage of the Earth's water is fresh water?" many of us reasonably overestimated the amount of freshwater on earth. Less than 10% of people correctly identified the proportion of fresh water on Earth was around 3%. Generally younger respondents, men and all those with a higher education were more likely to answer questions correctly, but the greatest decline in scientific knowledge was also in the younger respondent age group. Less educated and older people are more likely to think that humans lived during the time of the dinosaurs. Slightly more than 73 % of respondents in 2013 knew that the earliest humans did not roam with the dinosaurs, which was a small increase from the 70% of correct responses recorded in 2010.

When the results of this survey were released, some of the media created headlines which suggested that Australians had a dinosaur level of science understanding and depicted the earliest humans roaming on the earth with *Tyrannosaurus rex*. Such headlines provide support for the idea that it is easier to present information using sensational headlines than to delve into the meaning of the survey results. Do the results of this survey really provide evidence that Australian's lack understanding of scientific and zoological knowledge and should be treated as though they are getting dumber about zoology and science in general? The answer to this question depends on whether you consider that the survey had the right questions. Some of the answers to the questions on the survey were open to interpretation. For example, it might be reasonable to overestimate the amount of freshwater on earth given that it is such a small figure at 3%. We argue that even those Australians who got the right answers were given the wrong questions. The questions in the survey were a mismatch between the aims of the survey i.e. what do Australians know and understand about science? and the questions asked i.e. what facts can Australian's recall about Science? Although it may be valuable to assess the scientific and the zoological thinking of knowledge of the Australian public, it would be better, but perhaps more difficult to assess how Australians interpret and use data to make decisions about conservation of the environment and biodiversity.

Overall these types of surveys are pre-determined to arrive at the conclusion that the public is in deficit. A deficit model of communication is the tendency of the scientific community in general and zoologists specifically to think that the public suffer from a deficit of knowledge and are incapable of grasping the complexity of science, including the zoology discipline (Bauer *et al.* 2007; Pouliot and Godbout 2014). The deficit model in the long term develops public mistrust of science disciplines, and scientists (Hunter 2014; Pouliot and Godbout 2014).

Whether this was the right survey and whether the questions were the "right" or "wrong" questions to ask, the Australian Academy of Science did ask one question which the majority of Australian's answered correctly i.e. "In your opinion, how important is science education to the Australian economy?" In 2013, around 79% of Australians said that science education is absolutely essential or very important to the Australian economy and this value is virtually unchanged compared to 2010 when it was 80%. It is significant to consider that 8 out of 10 people believe science education is absolutely essential or very important to the Australian economy because it means the majority of Australians, although they may not recall scientific facts, understand how important science education is to our nation. This positive message did not receive significant coverage in the media.

The narrative of decline

The narrative that the science pipeline is in decline in Australia is evidenced by Australian student performance in international tests in reading, mathematics and science literacy, enrolments in senior secondary science and mathematics, practices in science classrooms, professional standards of science teachers and standards of science graduates from tertiary institutions. During the past decade, the mean performance of Australian students on the Organisation for Economic Co-operation and Development (OECD), Programme for International Student Assessment (PISA) in mathematical and reading literacy declined significantly between PISA 2003 and PISA 2012 (reading 528 in 2000 to 512 in 2012 and mathematics from 524 in 2003 to 504 in 2012). At the same time the proportion of Australian low performers increased and the proportion of top performers decreased in mathematics. In reading, the proportion of Australia's top performers declined significantly and the low performers did not change significantly. Australian's mean score in scientific literacy did not change between PISA 2006 and PISA 2012, but we are still rated 16th in comparison to other OECD countries. We will know more about the performance of Australia students in science in PISA 2015 (Thomson *et al.* 2009, 2012). Australian student performance has declined so much in the last 12 years that we are now in the second tier on all measures of PSIA and our significant slide down the rankings is not anticipated to cease. Those amongst us who are optimists may argue that Australian students have fallen partly because other high performing Asian countries have been included or comment that we are educating more students than ever before, so we must have a tail end which increases and decreases our overall performance. At best, the evidence reports that student performance in science is static, while Asian countries such as Singapore and China Shanghai are extending their lead in reading and mathematics.

Other measures of international performance at lower primary and early secondary tell the story that the pipeline declines start early. The Trends in International Mathematics and Science Study (TIMSS) and the Progress in International Reading Literacy Study (PIRLS) are international studies directed by the International Association for the Evaluation of Educational Achievement (IEA). TIMSS, which focuses on assessment of content knowledge, has been conducted at years 4 and 8 on a four year cycle since 1995 and PIRLS, at year 4 on a five year cycle since 2001. The performance of year 4 Australian students is below that of the top-performing Asian countries in our region, England and the United States; Australia being a top 20 rather than a top 10 performer (Marginson *et al.* 2013). Over a 16 year period the performance of year 8 students has remained static. Collectively these measures indicate that our youngest Australians may know less, and be less able to solve problems, than children in countries who are our nearest neighbours. These trends have been an important motivation for the Review of the Australian Curriculum (Donnelly and Wiltshire 2014). A dangerous idea might be to ignore all these international tests and allow our students to do other science and mathematics tests, such as the Educational Assessment Australia at the University of New South Wales (UNSW) or the Australian Council for Educational Research (ACER) in Melbourne. This may provide us with a better measure of how students, in our small population and isolated country, stand up against systems which "teach for the test". We are, however, not convinced by the idea of abandoning international tests, at least not yet.

The percentage of students enrolling in secondary science is decreasing, even though the absolute total numbers of students doing science is increasing. Ainley *et al.* (2008) found that in the period 1976-2007, the proportion of students enrolled in biology decreased from 55 to 25%, chemistry decreased from 29 to18% and physics almost halved from 28 to 15%. A recent report found that while the number of students enrolled in Year 12 increased by 30,800, or 16% between 1992-2012, there were 12,000 less physics and chemistry students, a decrease of 5% in chemistry, 7% in physics and 12,000, or 10%, less biology students (Kennedy *et al.* 2014). In mathematics, declines are not centered on student numbers, but rather the concern is that students are choosing the easier non-calculus based courses. The number of students completing the less advanced mathematics courses is increasing at the same time as the number of students in the advanced and calculus mathematics is decreasing (Kennedy *et al.* 2014). National fora on "*Assumed Knowledge in Maths: Its Broad Impact on Tertiary STEM Programs*" discuss the impact of this shift for student progression and performance at tertiary level. Overall they conclude that students entering chemistry, physics, engineering, mathematics, statistics and life sciences without the appropriate assumed knowledge in mathematics struggle with mathematics content in science and engineering subjects and experience very high failure rates, in some cases as high as 60% (King 2014).

It is depressing that many of the science curricula i.e. Nuffield, Harvard Physics Project, Science as Doing, written to engage students with science have not lived up to expectations. A survey of Year 11 and 12 students in New South Wales, South Australia and the Australian Capital Territory schools found that 92% of students stated that science was boring, difficult and irrelevant to their lives (Goodrum *et al.* 2011). They complained that the majority of time was spent transcribing text from textbooks, while a smaller amount was devoted to following recipe-like practicals to arrive at pre-determined outcomes. It is in the middle years of secondary school science where students get disenchanted and decide not to enrol in senior school science (Goodrum *et al.* 2001; Goodrum 2006; Rennie 2006; Tytler 2007; Cutler 2008). It seems to be a dangerous idea to acknowledge that the learning of science is difficult and effort is required to understand and learn zoology and science content more broadly. Instead we have been framing science learning as "fun", in the hope of attracting more students to science. The "fun" frame has not been effective because students eventually find out that it is not fun, (Keast *et al.* 2010). To be focussed on "fun" as the solution paints a fraudulent picture, especially because when learning science students will encounter difficult and counter-intuitive concepts. Although we disagree that difficulty must equal boredom. It is almost inevitable that if teachers are teaching outside their disciplinary expertise, and without sufficient resources, it will be challenging and a time-consuming process to come up with interesting strategies, especially for difficult science concepts, which they may also not understand.

At the next level of education the agenda, a widening tertiary participation (Bradley et al. 2008) has added to the idea that academic standards of science graduates are declining. It is very difficult, if not impossible, however, to determine if there is a decline in academic standards of science graduates when we have no starting measure to assess the standard of a science graduate. Perhaps our perspective is formed by imagining a halcyon day when all our science graduates could solve problems by working in teams as a result of their excellent communication skills and extensive content knowledge. Was this ever the case? It is only since the Learning and Teaching Academic Standards (LTAS) project in Science funded by the Australian Learning and Teaching Council (ALTC) (now the Office for Learning and Teaching) defined more broadly the expected standards of Science graduates described in learning outcomes known as the Threshold Learning Outcomes in Science (STLOs) (Jones and Yates 2011) do we have a baseline from which to measure. These STLOs were set as a reference point by the Higher Education Standards Panel (HESP). The sub-disciplines of Biology have modified the STLOs and developed the Biology Threshold Learning Outcomes (BTLOs) which describe what a biology/zoology student should know and be able to do (Ross et al. 2014). Similarly, the biomedical science discipline network, Collaborative Universities Biomedical Education (CUBEnet) has developed the Biomedical Threshold Learning Outcomes. For decades the Australian Council of Deans of Science (ACDS) has been tracking graduate destinations in enrolments at tertiary level science (ACDS 2003; Harris et al. 2012). As technology and potential deregulation change, student and community expectations of the value of a higher education degree, the value of the on-campus experience for science and zoology graduates is set to shift in ways which universities globally are trying to conceive (Barber et al. 2013; Johnson et al. 2014). The pervasive idea of our graduates are not what they used to be is in contrast to examples where our young are excelling. Two recent examples are team Echidna to Harvard (http://www.abc.net.au/news/2014-09-30/team-echidna-first-australians-to-compete-at/5780498) and a team of undergraduate engineering students at the UNSW who smashed the world speed record for electric vehicles http://www.worldsolarchallenge.org/. These students are talented and motivated undergraduates, likely to go on to being creative problem-solving scientists.

The evidence against the narrative of deficit and decline

Although the deficit and decline narrative is widely used, it is clear that on a number of intelligence metrics we have increased. In literacy we are doing better as a nation. We had some significant increases from our lowest level, so we are all much better able to handle literacy problems than earlier generations, who left school at 12 and 14 (ABS 2013). In terms of generational movements in IQ, we are also getting smarter. Enrolments in school have never been as great and enrolments in the tertiary sector have increased since 1949 from about 31,000 to now to over a million. Do we really understand less science and technology when it has never been so pervasive? We are communicating at previously unimaginable distances and speed and the publication rate of science is growing exponentially, doubling every 15 years; greater than at any other time in our history (Churchill 2014).

The narrative of deficit and decline has also not been effective in abating declining research funding for Australian science nor useful conversations about the direction of Science education. In contrast to intent, deficit narratives are creating dangerous dichotomies. For example, the comments of research scientists in the "Review of the Australian Curriculum" (Donnelly and Wiltshire 2014) aid to further dichotomise the debate and undermine educational research. Simplifying and trivialising education research can ultimately stifle more thoughtful solutions.

> *"The science curriculum's focus on inquiry-based learning, and the de-emphasis of knowledge would indicate that the curriculum shaping process has been heavily influenced by modern educational fads which are pushed on the community largely by university education faculties".*
>
> Professor Peter Ridd p.184

This dangerously misleading view demonstrates a limited understanding of the research of learning sciences (National Academies Press 2005). As scientists, we need to be careful that when we enter debates around the science of learning and education, we can be scholarly naïve and be our own worst enemy.

As Bruce Alberts, the recent past Editor-in-Chief of the journal *Science*, stated in 2009,

> *"Scientists may tend to blame others for the problem, but strange as it may seem, we have done more than anyone else to create it"*

Inquiry-based learning neither de-emphasises knowledge nor is it a modern educational fad. It is almost pre-historic. Inquiry-based learning was proposed by the philosopher, psychologist and educational reformer John Dewey (1897), someone seemingly hopelessly addicted to fads. Dewey (1916) suggested that inquiry should be used so that students "do" science, like scientists do using the process of science, rather than solely learning science facts. If we remove an inquiry-based learning pedagogy from science, then we will be shifting our science pedagogies to pre-1897. Rather than removing active science inquiry, incorporating inquiry-based learning in all science classes is the right direction (Ross and Gill 2011; Alberts 2013. Doing this, however, does not discount that learning science facts that can be accessed automatically is critically important. It has long been acknowledged that it is extremely important to access 'facts" when required with sufficient knowledge to be discriminating about the accuracy of the information accessed. Being able to regurgitate a "fact" for a survey or quiz show does not reveal the value in having science knowledge. For example, with continued climate change and melting of the ice caps, sea level rise and continued degradation of freshwater, in 2020 a new estimation may show that 3% is no longer a good estimate for the earth's freshwater. It is the utility of the knowledge in this context which becomes important. Students need the ability to make decisions based on data with its inherent uncertainties and variability (Holmes *et al.* 2014).

If we do not attempt to move beyond the deficit narrative then we will continue to have review recommendations which suggest there has been an ineffective pedagogy such as inquiry-based learning where the pendulum has swung too far and the dangerous and retrograde solution creates a dichotomy in this instance explicit teaching. It is dangerous to swing in the other direction and go back to basics and the explicit teaching of science. While some explicit teaching is required, it should not preclude inquiry-based learning. It is neither one nor the other. We should not be arguing over and over again whether the solution is between constructivist/ inquiry versus explicit/ traditional pedagogies. This debate only provides momentary satisfaction in the belief that a solution has been found. The reality is that learning science and mathematics is hard. Both disciplines are filled with counter intuitive concepts which are difficult to understand, but which can be understood. To improve science education we need good teachers who have pedagogical content knowledge (Shulman 1986), high expectations for their students, create high warm environments where productive science learning occurs and have an understanding and experience of science research.

Dangerous solutions

We have suggested throughout this conversation that it is dangerous to continue the deficit and decline narrative to support Australian science. Australians value science education. It is similarly dangerous to ignore our international ranking both in the performance of Australian students and science strategies. It is dangerous that we are the only country among the members of the OECD without a science and technology strategy. In this dangerous future, our previous chief scientist Ian Chubb (2012, 2014a) stated that the solution was to organise, evaluate and cohere in a strategic way because science education has a central role in securing Australia's competitiveness (Chubb 2014b).

In most recent times, this message has gained traction from the Australian Industry Group who in March 2015, stated:

> *"There is a need to give priority to inquiry-based learning and the development of problem-solving and higher order thinking skills" p 19*

Then Price Waterhouse Cooper in April 2015 stated:

> *"Thinking and problem solving, analytic capabilities, curiosity and imagination*
>
> *have all been identified as critical 'survival skills' in the workplace of the future. p 14*

> *Driving change through the education system is challenging. And in the case of STEM it needs to begin with a clear, shared understanding and belief in the importance of the challenge and the innovation outcomes we're striving p 21*

The appointment of the new Australian Prime Minister Malcolm Turnbull, the National Innovation and Science Agenda (2015) and the appointment of the new Chief Scientist, Alan Finkel, has fuelled hope that science and science education will become central to the political agenda. Headlines such as "Malcolm Turnbull will save Australian science?" and statements from him such as

> *"a country that invests in science and puts it right at the centre of our national agenda"*

are promising, but others caution us not to become too excited (Copeland 2015).

This caution is because once a deficit dialogue has become entrenched it is difficult to move beyond (Bauer *et al.* 2007; Hunter 2014; Pouliot and Godbout 2014). Bauer *et al.* (2007) describe the significant attempts to re-frame the deficit model, while Pouliot and Godbout (2014) provide a co-production model which proposes scientists and non-scientists as different but equal and equally capable. In a community where zoologists and scientists mostly interact with other zoologists and scientists; zoologists and scientists need to cross boundaries and connect their disciplinary expertise with experts in the learning sciences and education.

Science educators and science researchers also need to rethink strategies to make science learning and secondary level science more accessible and interesting. The iSTEM syllabus (Integrated, Skills, Technology, Engineering and Mathematics) is a good example of a new curriculum with a strategy of engaging and creating meaningful experiences for students through collaborative partnerships (Sleap *et al.* 2013). Such curricula cut across the traditional disciplinary boundaries of Science, Technology and Mathematics departments in schools .

It is unlikely that science will become easier to learn, but science is understandable, is interesting and is not just for the brightest. To do this we need professional development for our primary and secondary school mathematics and science teachers. Many of our young teachers are saying they are underprepared when entering the classroom (McKenzie *et al.* 2014). We need to be more creative when we teach science and we need to work towards demystifying the "mystique of science" which often creates a barrier in science learning (Lemke 1990; McWilliam 2009) and implement such initiatives as computer coding and requiring that new primary school teachers graduate with a STEM specialisation (National Innovation and Science Agenda 2015). After all STEM education provides as Alan Finkel recently stated:

> " *a way of thinking and understanding of the world around them that I think will serve them very well, whether they go into science or business or politics or the public service*",
>
> Dean (2016).

Scientists, however, need to be more careful about what we understand about science education in this current debate. Just because we understand our disciplinary expertise does not mean we can make full commentary on other issues in ways which are not helpful. Many leading journals such as Science and Nature are suggesting the first step is that scientists valuing science education as much as science research (Savkar and Lokere 2010; Anderson *et al.* 2011). Many of our science colleagues who are in education-focussed positions at major metropolitan universities have decided that educational research will be their focus and have insight and understanding of the issues facing the tertiary science sector. It is time to value them rather than treat them as failed science researchers. For those of us who are science researchers, it is important to recognise that although good at research, we may not be as familiar with science learning pedagogies and we may need training in education.

Rather than present the declines in student performance in international tests with doom, we need to provide actions and resources to improve the enrolments in secondary science. For those students who continue on into research more research funding is required to ensure career pathways. Currently many of our best and brightest postdoctoral fellows, with substantial research training, cannot find jobs and cannot contribute. For those students who will exit as graduates we need to ensure they are work-ready and experiences in their undergraduate careers have prepared them for a future which will require them to be technological and savvy entrepreneurial.

As the futurist James Martin responded in the "The meaning of the 21st century" (2007, p. 10)

> *"If you were to pick any time in history to be alive, which time would you pick?" He answers: "If I could choose any time to live, I would want to be a teenager now. There is excitement in the air – perhaps more excitement than at any other time…" Many people react to this by saying "you've got to be crazy" We're trashing the planet and there'll be extreme tensions caused by over population and over--consumption… We have terrorism, weapons of mass destruction… even the catastrophe of a roasted planet…" Martin continues undeterred: "more than at any other time, young people will make a spectacular difference. Revolutionary change is essential and today's young people will make it happen. There needs to be a crusading determination to bring about the changes we describe. Today's young people will collectively determine the outcome of this make--or--break century. If they understand what is possible, the Transition Generation can open up a highway to by far the most creative in history".*

This is a narrative of what is possible rather than what is depressingly negative. This is a strategy. As Bruce Albert's editorialised in the journal Science "*the aim is nothing less than a more rational world*". In our view, to continue with the deficit and decline narrative is likely to create more ineffective than effective solutions. It's time to change the rhetoric to ensure the science and innovation we need for Australia.

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